Can We Sequester Large Quantities of Atmospheric Carbon in the Arctic Permafrost?

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Introduction

- A band of Boreal Forest stretches around the Northern Hemisphere land masses. The northern section of this forest becomes stunted trees which thin out, and muskeg (bog) begins to appear. This area is called the Taiga. Still further north, the trees give way to the Tundra.
- The Arctic Tundra covers 13 million square kilometers, and is underlain by permanently frozen ground, or permafrost. The surface of the tundra comprises a thin layer, which is thawed and frozen during an annual cycle.
- The plants that grow in this “active layer” have adequate water and a reasonable amount of sunlight, but have a very small supply of nutrients. Since the tundra plants are underlain by permanently frozen ground, the only nutrient supply is via the air.

Sequestering Atmospheric Carbon in the Permafrost

- If some way could be found to supply nitrogenous fertilizer to these plants, it would lead to a great increase in the plant production rate. This would raise the level of the surface, which in turn would raise the surface of the permafrost, since the active layer is of constant thickness. This would lead to the permanent sequestration of atmospheric carbon in the permafrost.
- This presentation suggests how this might be done on a scale that could make a large contribution to the mitigation of the Greenhouse Problem.

Arctic Tundra

Tundra in Denali National Park and Preserve, Alaska.
Fridmar Damm/Leo de Wys, Inc.
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What Is The Tundra?

Tundra, generally defined as low-growing vegetation including shrubs, grasses, sedges, mosses, and lichen, covers the plains and coastal regions of the Arctic.

A Year On A Tundra Bog (Muskeg)

- By the end of an Arctic winter, everything is completely frozen. During the summer, the surface of the Arctic bog thaws. This thawed layer is called the active layer and its thickness is a constant for a given climate regime.
- The region under the active layer remains permanently frozen and is called permafrost. It may be hundreds of feet thick.
- If the surface of the active layer could be made to rise (through increased plant productivity—increased dry matter production), the surface of the permafrost would rise by the same amount, since the active layer has a constant thickness.
- The rising of the surface of the permafrost would trap organic matter, removing it from interacting with the atmosphere.

The Arctic Tundra As Seen By a Temperate Zone Agricultural Scientist

- The plant growth or dry matter production rates in the Arctic tundra are incredibly low – of the order of 10 lbs/acre/yr.
- Compare this to 5,000 lbs./acre /yr on temperate grazing land. The Arctic tundra has adequate water and comparable solar energy, albeit 24 hours a day and only in the summer. The problem is that the nutrient supply is extremely low. The tundra plants are underlain by frozen material and the only nutrient supply is via the air.
- Nitrogen is the limiting nutrient. The principal source of utilizable nitrogen is probably from the Aurora Borealis--a few pounds of N per acre per year.

Fertilizing the Tundra

- The most critical nutrient is nitrogen. If nitrogenous fertilizer could be added to these plants, the dry matter production rate would increase, and the surface of the peat would rise. This would cause the permafrost surface to rise, which would lead to the entrapment of large quantities of atmospheric carbon.
- The most economical source of nitrogen would be to operate high temperature gas turbines fueled by the abundant quantities of natural gas and methane-water clathrates found in the Arctic.

Fixation of Atmospheric Nitrogen by Heating Air to High Temperatures

- If atmospheric air is heated to high temperatures, for example by lightning, by the Aurora Borealis, by passing through an electric plasma arc, or in a gas turbine, nitrogen is oxidized to nitric oxide and nitrogen dioxide.
- In the natural environment, these rapidly convert to nitrate, and would result in very efficient foliar application (directly to the leaves) of nitrate to the tundra plants.
- The foliar application of this fertilizer could result in up to a hundredfold increase in the growth rate of tundra plants.

Fixation of Atmospheric Nitrogen In A Gas Turbine

- Nitrogen can be oxidized by direct combustion at very high temperatures. Since the reaction is endothermic, the proportion of oxidized nitrogen at equilibrium rises rapidly with the temperature. With the air at atmospheric pressure, the amount oxidized is 1.2 % by volume at 2000 C, and 5.3 % at 3000 C. This was the basis of the industrial fixation of nitrogen. (Birkeland-Eyde process, which used a plasma arc).
- Special high-temperature gas turbines could be developed using ceramic parts. By adjusting the temperature of operation of the gas turbines, the amount of fixation and hence the carbon dioxide composition of the Earth's atmosphere could be controlled.

High Temperature Gas Turbines

- The thermodynamic efficiency of a power station is proportional to the difference of the absolute temperature of the turbine and the absolute temperature of the discharge, divided by the absolute temperature of the discharge.
- Hence it is desirable for power plants to operate at as high a temperature as possible. In populated areas temperatures are limited by NOx emissions.
- In the Arctic tundra the soils, lakes and rivers are all very acidic due to the presence of humic acid. The overall reaction consumes atmospheric nitrogen and produces basic nitrogen compounds, which will lead to the overall reduction of total acidity.

What Evidence Do We Have That a Power Station Can Increase the Growth Rate of Tundra Plants?

- BP-Alaska has been operating gas turbines at its installation at Prudhoe Bay for the last 30 years. This installation is in the middle of the Central Alaska Caribou Herd range. In 1970, the herd had 3000 animals. At present, the herd has grown to 36,000—a twelve-fold increase.
- The arctic caribou herds range in distinct areas with little interchange of animals among herds.
- The Central Arctic Caribou Herd occupies a 15,000 square mile area around Prudhoe Bay.
- The adjacent herds have increased slightly but less than a factor of two.

Lessons From the Caribou

Photo by BP/Alaska

- The central arctic caribou herd range on 10 million acres in which is situated the BP-Alaska oil field operation at Prudhoe Bay.
- Assume that each caribou consumes 2.5 tons of above-ground dry matter per year. In 1972 the herd had 3000 members. This represents a "carrying capacity" of one caribou/3000 ac.
- This implies a dry matter production rate of 2 lb/ac for this tundra area in its original state. At present, the herd has increased by a factor of 12 – a remarkable feat by normal agricultural standards.

The Prudhoe Bay “Experiment”

- As stated earlier, the increase in the Central Alaska Caribou Herd could be interpreted as a sizable increase in the above-ground dry-matter production rate.
- There should be a new lens of peat in this area, which could prove direct evidence of sequestered atmospheric carbon.
- Clearly, the Prudhoe Bay “experiment” is an important pilot project and should be studied in detail. (Interestingly, BP Alaska has tried to keep its NOx levels as low as possible.)

How Much Carbon Can Be Sequestered?

- The increase in caribou numbers implies an above-ground dry matter production rate of 24lb/ac/yr. This represents an increase in the total production rate of 110,000 tons/year.
- To determine the amount of carbon sequestered, we should double this figure, since most plants have as much growth below the ground as above, and multiply by 0.4 (peat contains about 40% carbon).
- The implication is that the Prudhoe Bay turbines are sequestering 100,000 tons of atmospheric carbon per year. We might be able to increase this by an order of magnitude.

The Multiplier Factor

- If we burn one ton of carbon (as methane) in a gas turbine situated in tundra muskeg, how many tons of carbon will be sequestered as frozen peat? On the basis of passing the methane through at a 8% fuel/air ratio, and with the turbine operating at a temperature of 2000 C, we would fix 1.2% of the contained nitrogen, which would be ¼ ton.
- On the assumption that permafrost peat has a C/N ratio of 800 and that we lose half the nitrogen fixed (through denitrification and other losses), we might expect to remove 100 tons of carbon (as CO2) from the atmosphere. If the turbine could be operated at 3000 C, this number would be 440 tons of carbon sequestered for each ton of methane carbon burned.

Advantages of This Strategy in Mitigating the Greenhouse Problem

- It proposes a method of controlling, rather than reducing, the CO2 composition of the atmosphere.
- It can be done at no net cost to the public; in fact, it can be done at a profit.
- It will enhance and not harm the tundra ecosystem, which comprises 10% of the Earth's land surface.

The Dark Side--The Sword of Damocles

- Since the end of the last ice age, more than 400 gigatons of carbon has been accumulated as frozen peat in the Arctic permafrost. This represents more than 60 times the amount of carbon put into the atmosphere every year by humankind.
- If the temperature of the Arctic were allowed to rise (which seems to be happening now) the thickness of the active layer would increase, the surface of the permafrost would melt, and large quantities of carbon would be released to the Earth's atmosphere.
- Even if the temperature of the Arctic rises, we could still prevent the permafrost from melting by making the surface plants grow more rapidly, as is previously described.

A View of the Future

- The tundra would have methane–burning gas turbine power stations at 200 mile intervals on large natural gas pipelines. The turbines would be large and high-temperature, designed to throw their plume high into the atmosphere to get as much coverage as possible. As the productivity rises, other nutrients may be required (e.g. trace elements) and a solution of these could be sprayed into the turbine discharge.
- Transmission lines would send electric power to southern population centers. The increased productivity of the tundra would enable reindeer (a domesticated version of caribou) and musk-ox ranching, adding to the Arctic economy and providing an additional source of high-quality protein for marketing to the world.
- The gas turbine stations would be adjustable to control the carbon dioxide composition of the atmosphere to produce an optimum temperature for the Earth – which might be different than that of the present.